DYNAMICS OF THE OZONE LAYER IN THE SOUTHERN HEMISPHERE BASED ON SATELLITE DATA

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Satellite data – the "zonal means" – are used to study the processes of formation and disappearance of the Antarctic ozone anomaly (AOA). During the formation of the AOA in September-October, the masses of ozone are transported from the polar region to the middle latitudes of the Southern Hemisphere. In November-December, the AOA is filled with ozone moving from the middle latitudes. The same mass of ozone, reaching more than 70 million tons, is transported from the polar latitudes to middle latitudes and back. No signs of ozone depletion were detected in the Southern Hemisphere in September-December.

Space monitoring, satellite data, dynamic atmospheric processes, polar vortex, ozonosphere, Antarctic ozone hole

The part of the stratosphere where total ozone (TO) is below 220 Dobson units (DU) has been conventionally called the ozone anomaly (ozone hole). The discovery of the Antarctic ozone anomaly (AOA) was announced in 1985 [1] although there is evidence suggesting that the AOA had also occurred in the previous decades. The authors stated that the anomaly resulted from ozone depletion caused by chemical reactions including ones that involved Freon gases. In 1986, however, Stolarski and Schoeberl showed that during 1979-1982, the amount of ozone from 44°S to the South Pole remained almost unchanged from August through November. Total ozone loss close to the pole in September was balanced by ozone increase in the middle latitudes, and TO variations were caused by the dynamic redistribution of ozone rather than by chemical processes [2]. Unfortunately, that discovery was not accepted by the scientific community. We are not aware of any other publications in international journals on dynamic processes occurring during AOA formation. The issue appears to be closed. Subsequent research of the AOA was mainly aimed at proving that it was a human-caused phenomenon.

The NASA site [3] provides not only the digital maps of ozone but also the so-called *zonal means*. The surface area of Earth between the poles is divided into 5°-wide rings, and the TO mean is given for each ring. Usual programs (such as EXCEL) can be used to make graphs of latitude dependence of zonal means. Such graphs are shown in Figure 1.

Figure 1 A illustrates the spring redistribution of ozone masses in the Southern Hemisphere. In early spring, TO clearly decreases at the South Pole, and the "ozone anomaly" develops. Meanwhile, in the middle latitudes (40-55°S), total ozone increases, which can be attributed to ozone masses transported from the polar region. In the graphs in Figure 1 A, there are no satellite data for latitudes higher than 60°S for 1 August and 65°S for 15 August, as at these latitudes, the stratosphere was not illuminated by the Sun, and satellite sensors could not measure TO there. From mid-October onwards, the polar region is being filled with ozone, which is transported from the middle latitudes. Reverse redistribution of ozone masses occurs (Fig. 1 B).

We discussed the mechanism of redistribution of ozone masses in a previous study [4]. In the Southern Hemisphere, a giant polar vortex overlies polar and middle latitudes. From August through November, this vortex is an anticyclone, and its centre is in the polar region. Ozone fluxes (together with air currents) move away from the pole in all directions, rotating eastwards due to the Coriolis force. Thus, a rapidly rotating "ring" of the vortex is formed in the middle latitudes, accumulating ozone from the polar region. Ozone concentration inside the vortex drops dramatically, and a region with a decreased ozone content, including the AOA, is formed over the pole. At the same time, in the ring at middle latitudes, the ozone level is high. By the end of spring, the Antarctic stratosphere warms up, the vortex turns into a cyclone, ozone masses move back from the ring to the polar region, and the anomaly disappears.

As no satellite data on ozone levels in the polar region in August and September are available, the process of the ozone mass transport from the polar region to the middle latitudes cannot be studied. However, there are data for October and November, and the amounts of ozone that left the polar region and "excess" ozone in middle latitudes can be compared. Will this excess ozone be enough to fill the anomaly?

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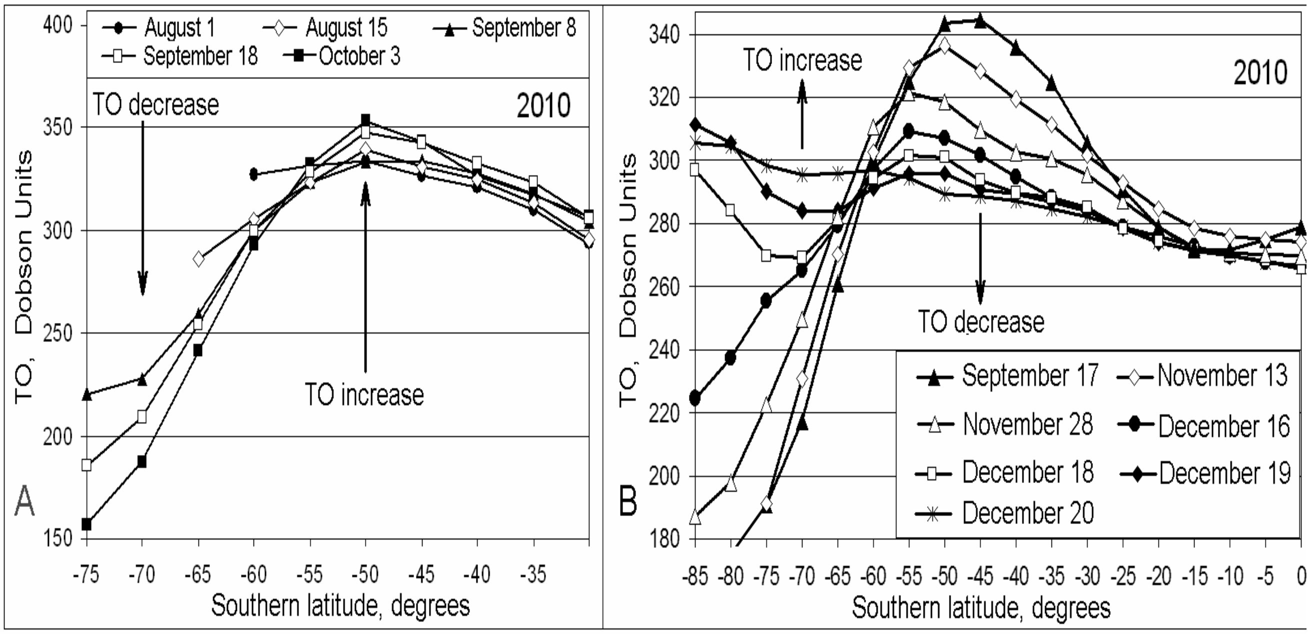

Fig. 1. Spring redistribution of ozone masses in the Southern Hemisphere

In Figure 2, the amount of total ozone in the Southern Hemisphere in 2010 obtained using the zonal means is shown by the dashed line, and results of averaging zonal means at different latitudes between 2 and 25 October 2010 are shown by the solid line. In October, the regions close to the pole clearly contain TO levels below the "threshold value" (the – sign) shown by the dashed line. The regions between 25° and 60°S contain TO above the "threshold" (the + sign).

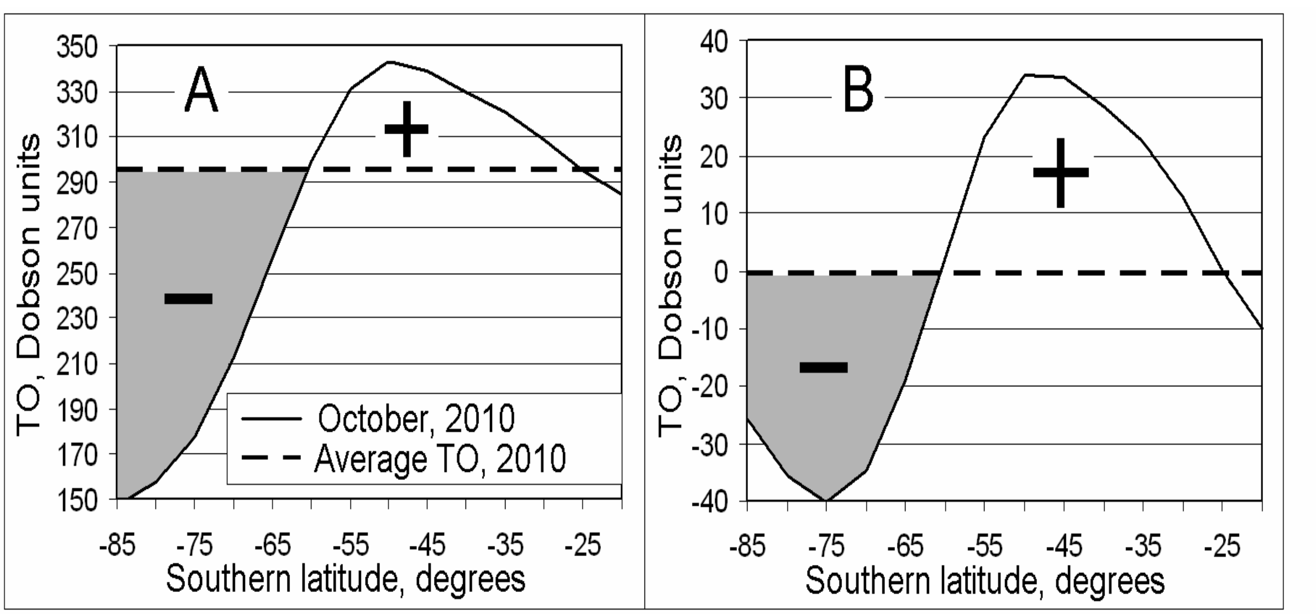

Fig. 2. The average TO in the Southern Hemisphere (dashed lines) in 2010 compared to zonal means averaged over October before (A) and after the adjustment (B)

To determine the ozone mass in regions (–) and (+), we adjust the data in Figure 2. First, we subtract the "threshold value", 296 DU, from the October data. Second, we take into account that zonal means have been obtained as TO data for a set of 5°-wide rings.

All rings have different circumferences, determined as $S = 2\pi R_0 \cdot \cos\varphi_i$, where R_0 = 6371 km is the mean radius of Earth and φ_i is the mean width of the i^{th} ring. To compare the amounts of ozone in the rings, the i^{th} zonal mean for October in Figure 2 A should be multiplied by cos φ_i. The results of adjustment are shown in Figure 2 B. Then, the residual TO values are summed for regions (–) and (+). In our study, the sum for region (–) is x_- = 148.3 DU, and the sum for region (+) is x_+= 157.0 DU. These values are close to each other (the difference near 6%), and, hence, total ozone remains almost unchanged. One can find that for region (–) the ozone mass M_- = 70.6 million tons, and for region (+), M_+ =74.8 million tons. M_- is higher than the ozone deficit in the AOA in 2010 – 26.58 million tons [5]. This is not surprising, as the deficit is the amount of ozone by which the ozone level in the Antarctic ozone anomaly is less than 220 DU. In 2010, from August to November-December, more than 70 million tons of ozone moved from the polar region to the middle latitudes and backwards. By way of comparison, in 1980, M_- = 33.7 million tons, and M_+ = 47.6 million tons. The area of the AOA was 3.35 million km^2 in 1980 and 22.6 million km^2 in 2010. In 2015, M_- = 74.4 million tons, and M_+ = 75.6 million tons. Calculations were based on zonal means averaged over October, and a "threshold value" was established for each year. October is the month of the TO maximum in the Southern Hemisphere, but the ozone anomaly occurs at about the same time. It is not related to ozone depletion.

The yearly minimum of TO in the Southern Hemisphere is observed in February – March. In this period, the stratosphere is illuminated by the Sun, and ozone is destroyed via photochemical processes involving natural and, probably, synthetic substances. Figure 3 shows a graph of zonal means averaged over February; the dashed line denotes the threshold value of 296 DU. No redistribution of ozone is possible. Later, in August – September, the ozone layer is recovered, mainly due to the inflow of ozone masses from the tropical latitudes.

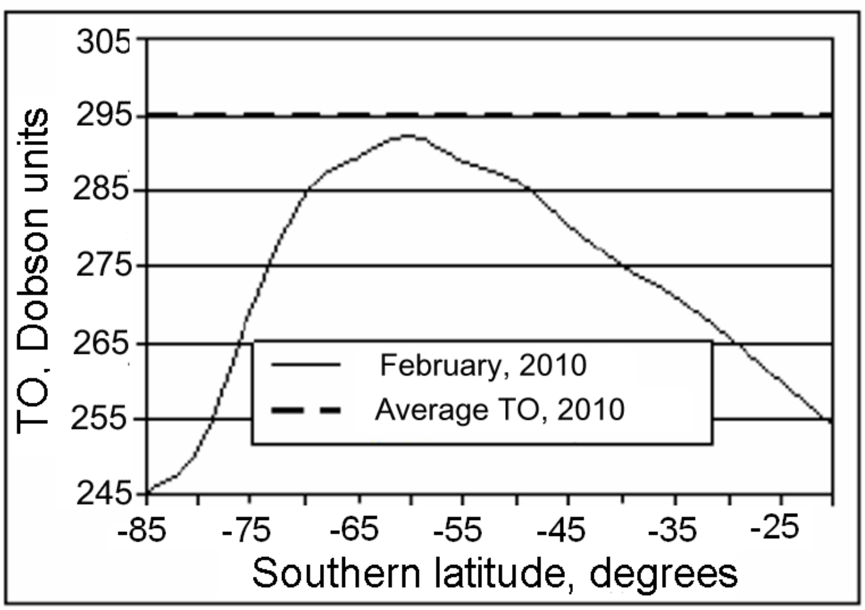

Fig. 3 A graph of zonal means averaged over February 2010; the dashed line shows the "threshold value" – 296 DU

Our actual results support Stolarski and Shoeberl hypothesis about the formation of an ozone anomaly over Antarctica as a result of the redistribution of ozone between the polar and middle latitudes in the southern hemisphere in the spring 1979-1982.

The next problem is the discovery of the atmospheric mechanism, which led to the emergence of a global spring anticyclone in the high and middle latitudes of the southern hemisphere. The study of this mechanism can give an answer to the question under what conditions and when the Antarctic ozone anomaly may disappear.

References

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